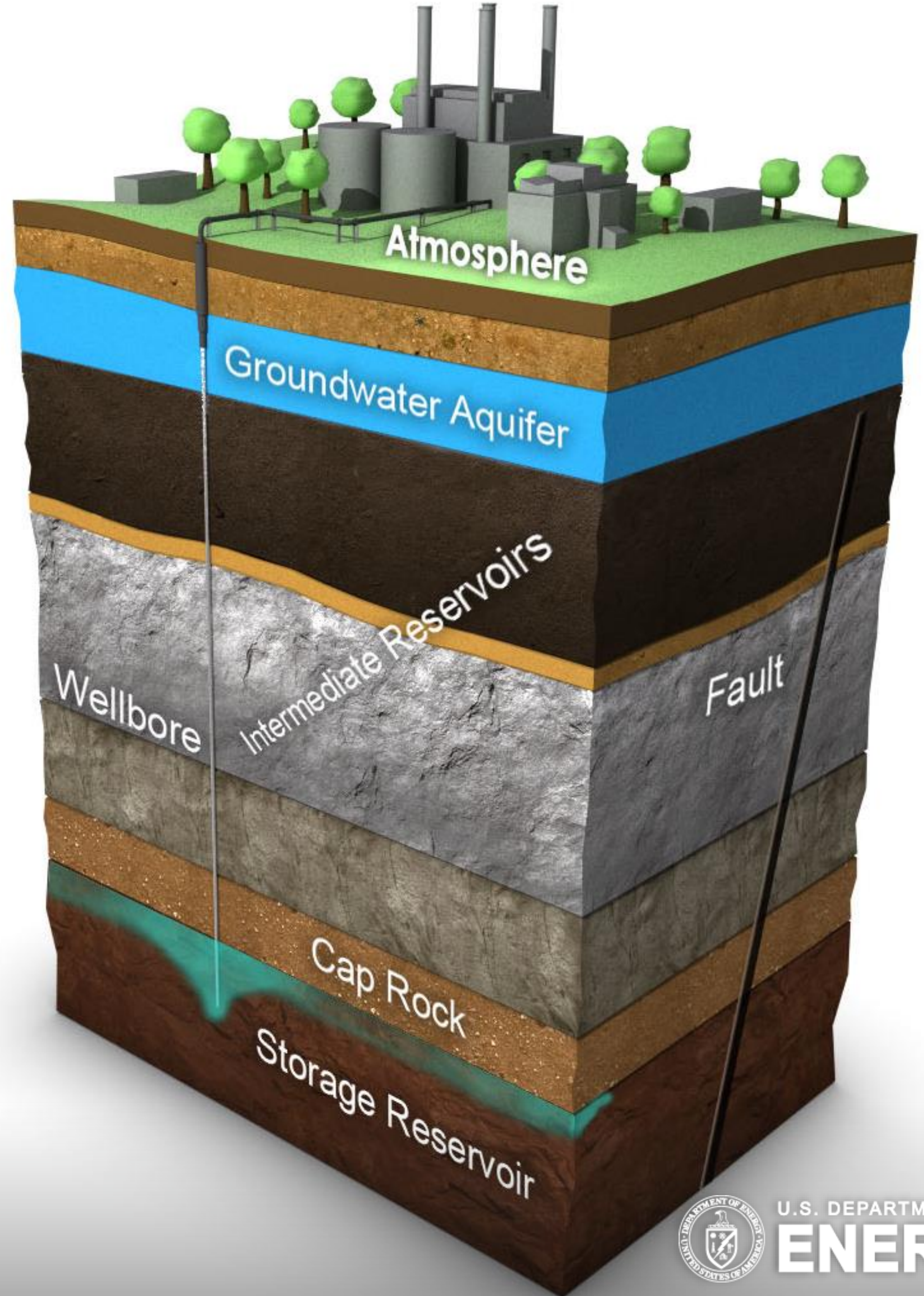
Optimal Design of Microseismic Monitoring Network

Presented by: Lianjie Huang
Los Alamos National Laboratory
(Yu Chen, Ting Chen, Kai Gao, and Lianjie Huang)

at the 2021 GWPC Annual Forum

September 29, 2021



Objectives

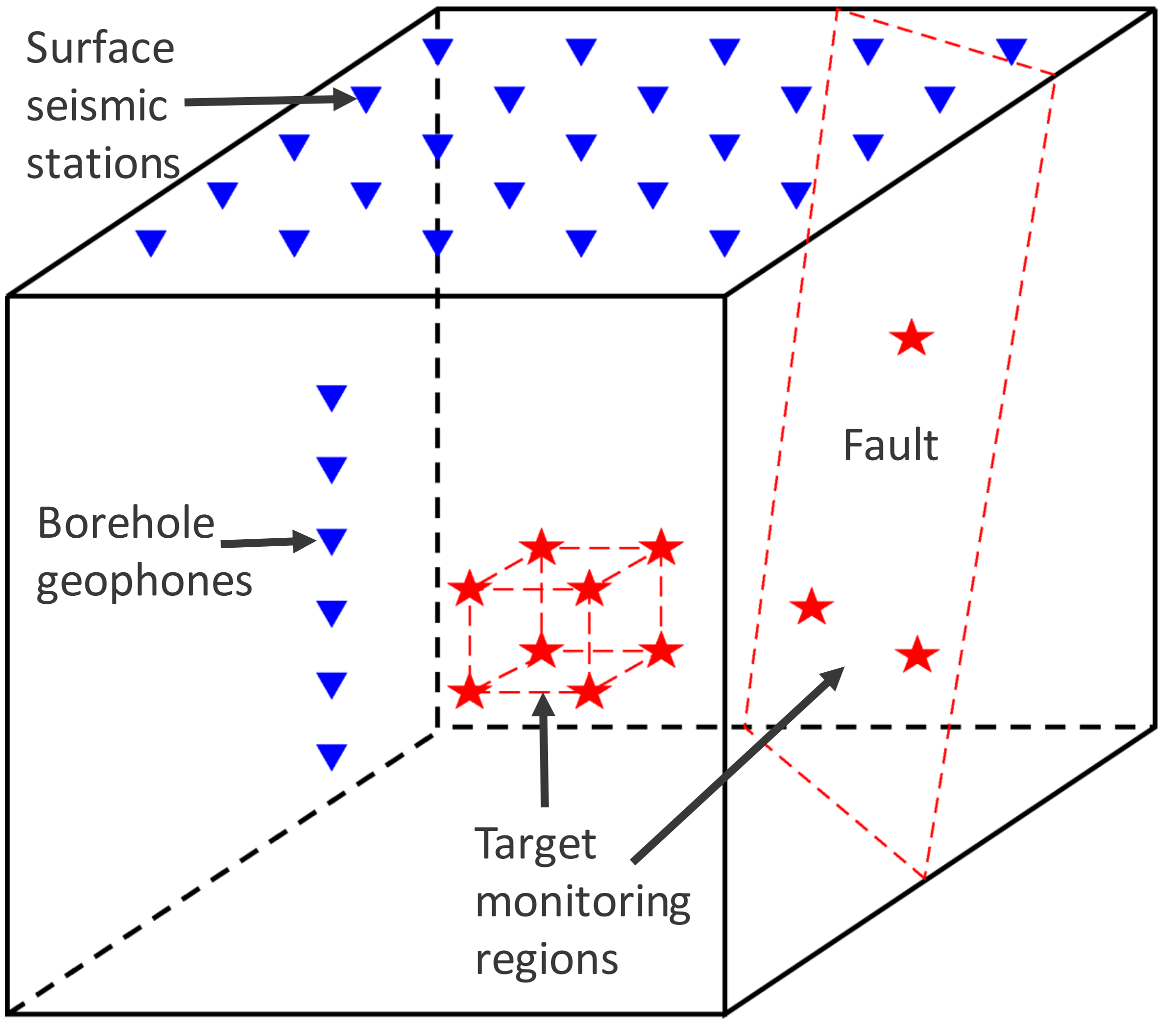
- Develop a tool for optimal design of microseismic monitoring network using surface and/or borehole geophones for cost-effective microseismic monitoring at geologic carbon storage sites.
- Demonstrate an example application of the tool to the Farnsworth CO_2-EOR field, Texas, the field demonstration site of the Phase III of the Southwest Regional Partnership on Carbon Sequestration.

Contents

- The NRAP tool: Optimal Design of Microseismic Monitoring Network
- Example application to the Farnsworth CO_2-EOR field, Texas

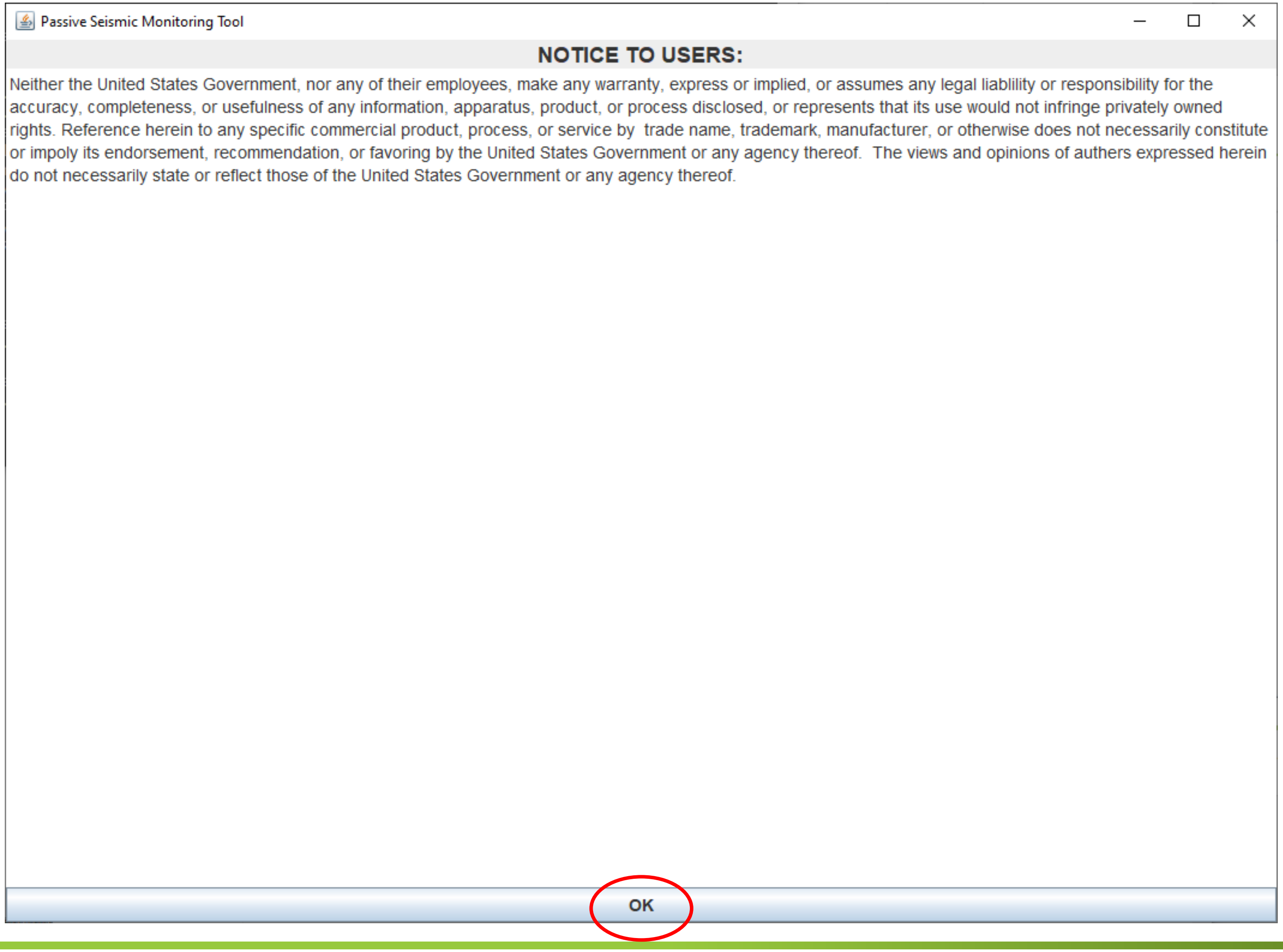
Method

- Design an optimal monitoring network to reliably locate induced microseismic events cost effectively.
- Based on the relationship between the hypocenter uncertainty of microseismic events (red stars) within a target monitoring region (red dashed box) and the geophone distribution (blue triangles).
- Applicable to any geologic carbon storage sites and other microseismic monitoring applications.
- Can use surface seismic stations and/or borehole geophone arrays.



NRAP Tool

- The GUI of the NRAP tool is designed by MATRIC | Mid-Atlantic Technology, Research & Innovation Center, with executable files from LANL
- Tool can be run on Linux, Windows, and Mac OSs
- GUI is based on java
- java -jar ./NRAP_PSMT.jar
- Click “OK” button



NRAP Tool

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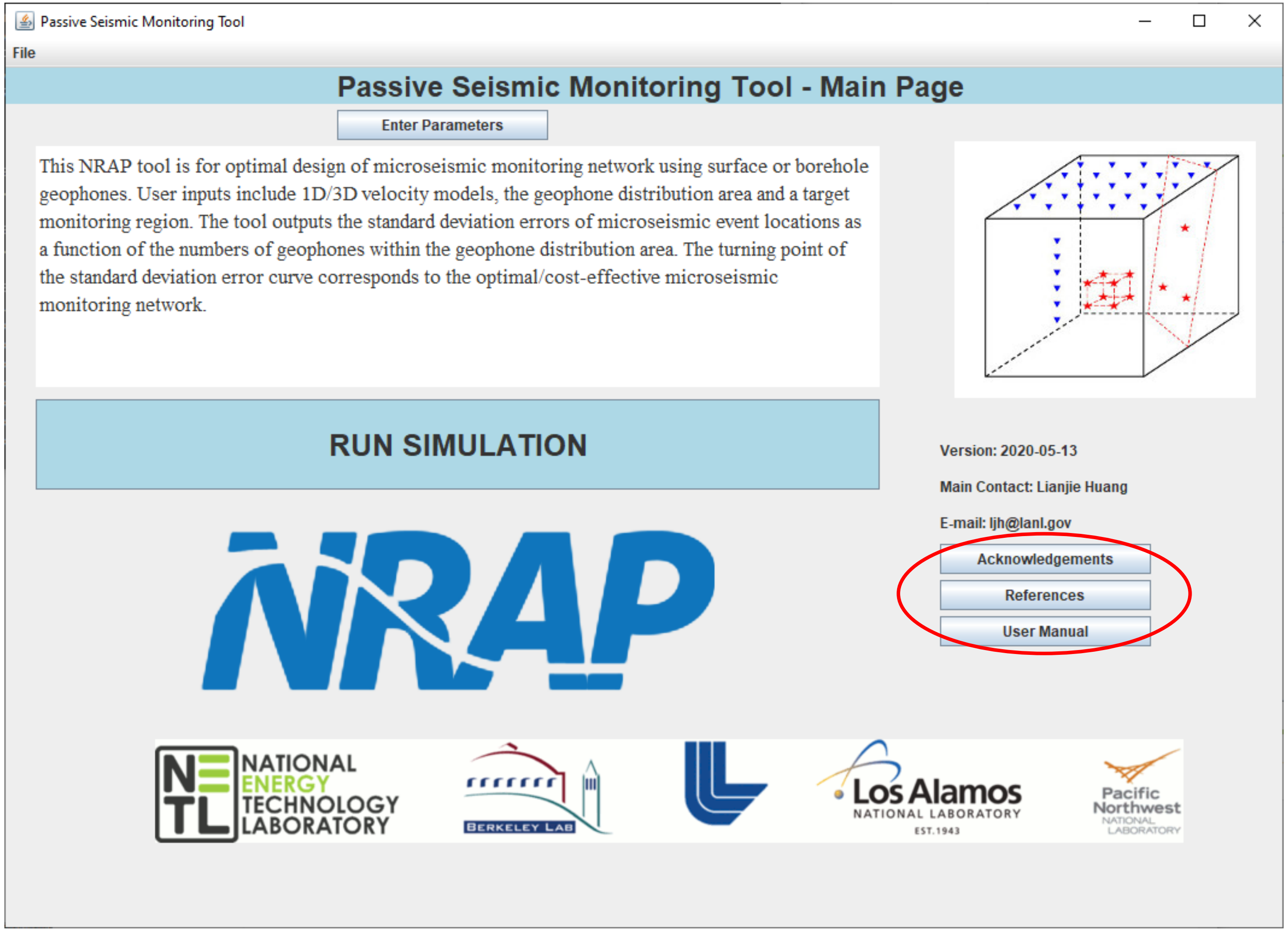
- Tool can be run on Linux, Windows, and Mac OSs
- java -jar ./NRAP_PSMT.jar
- Acknowledgments
- References
- User Manual



NRAP Tool

Application Acknowledgments

This work was completed as part of the National Risk Assessment Partnership (NRAP) project. Support for this project came from the U.S. Department of Energy's (DOE) Office of Fossil Energy's Carbon Storage Program. The authors wish to acknowledge Mark Ackiewicz (Division of CCS Research Program Manager), Traci Rodosta (Carbon Storage Technology Manager), Kanwal Mahajan (Carbon Storage Division Director), and M. Kylee Underwood (NRAP Project Manager). We also acknowledge the technical guidance of the NRAP Executive Committee, and the comments and feedback of beta tool testers from the international CCUS community.

NRAP Tool

Application References

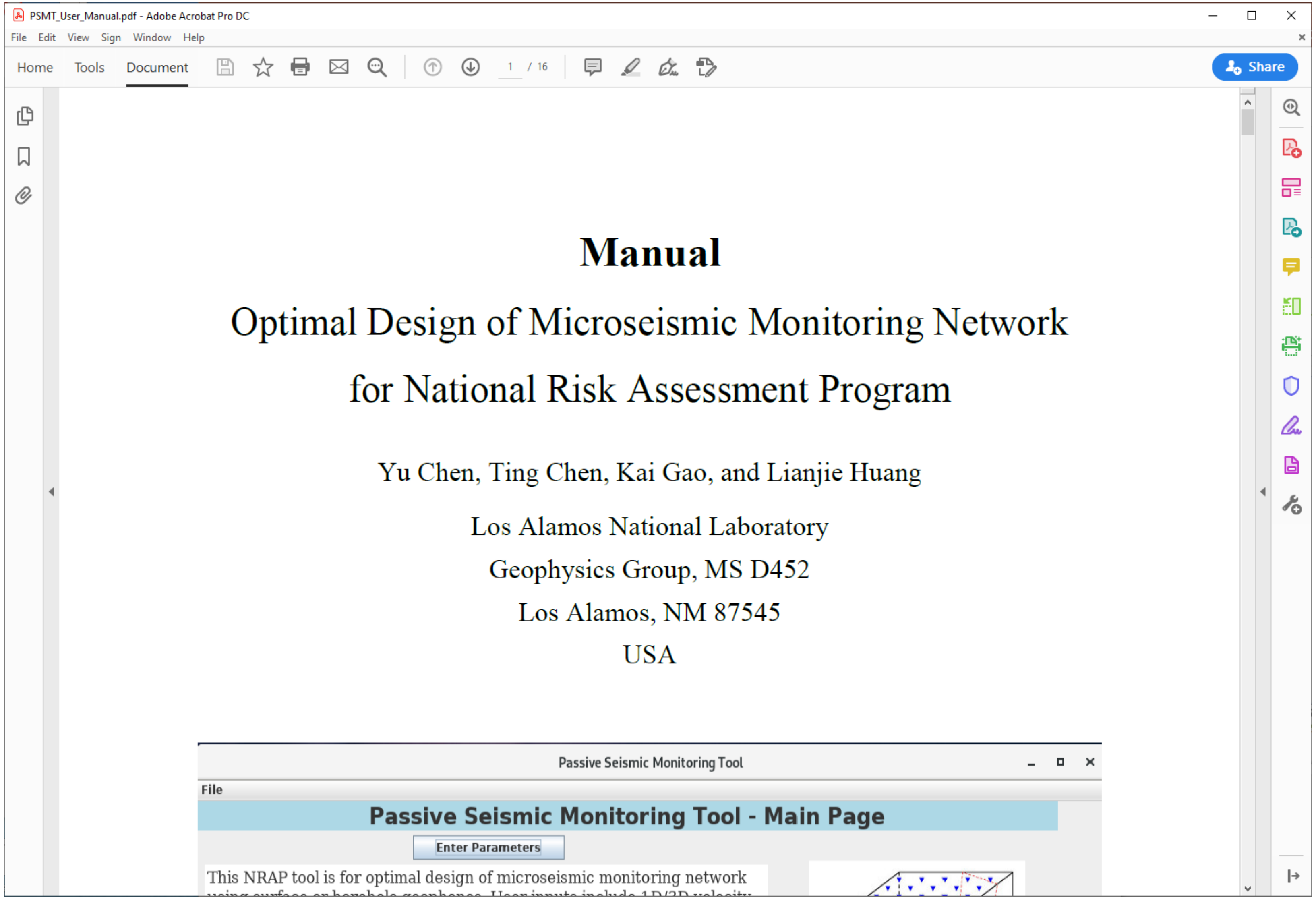
Chen, T. and L. Huang, 2020. Optimal design of microseismic monitoring network: Synthetic study for the Kimberlina CO2 storage demonstration site, International Journal of Greenhouse Gas Control, 95, 102981-1-8, https://doi.org/10.1016/j.ijggc.2020.102981.

Chen, Y., L. Huang, and E.C. Team, 2019. Optimal design of 3D borehole seismic arrays for microearthquake monitoring in anisotropic media during stimulations in the EGS Collab project, Geothermics, 79, 61-66.

Chen, T., L. Huang, W. Foxall, and J. Wagoner, 2016. Optimal design of a passive seismic network for monitoring CO2-injection-induced seismicity, the 15th Annual Carbon Capture, Utilization & Storage Conference, Tysons, VA.

Huang, L., T. Chen, Y. Lin, W. Foxall, L. J. Hutchings, C. E. Bachmann, and T. M. Daley, 2014. Design of an optimal microseismic monitoring network: synthetic study for the Kimberlina CO2 storage demonstration site, AGU Fall Meeting, Abstract S31A-4372.

NRAP Tool



Manual

Optimal Design of Microseismic Monitoring Network for National Risk Assessment Program

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USA

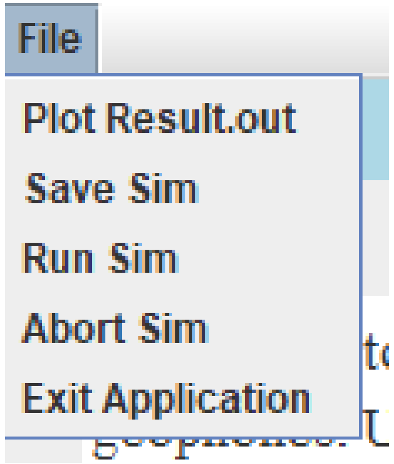
Passive Seismic Monitoring Tool

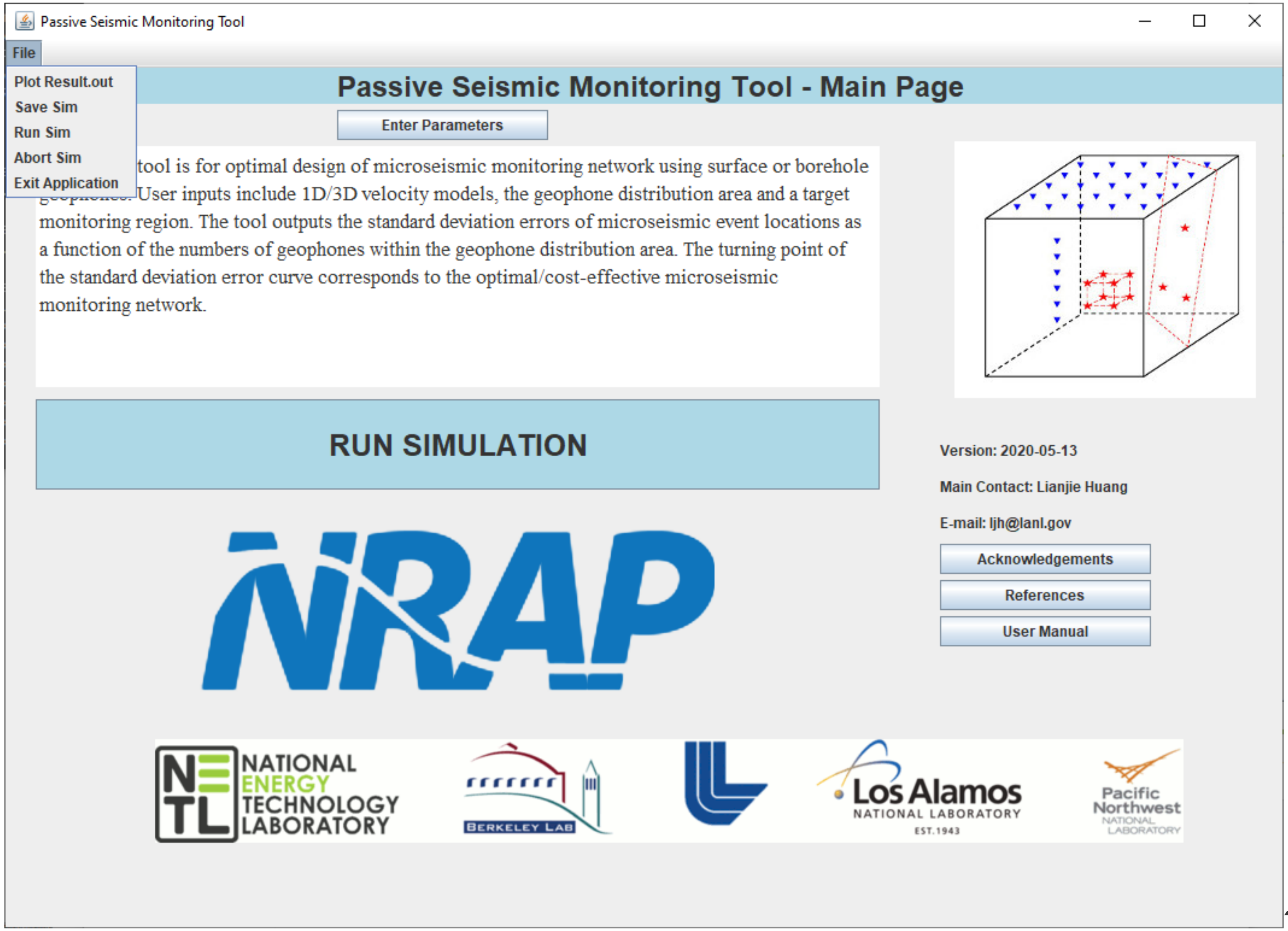
Passive Seismic Monitoring Tool - Main Page

Enter Parameters

This NRAP tool is for optimal design of microseismic monitoring network

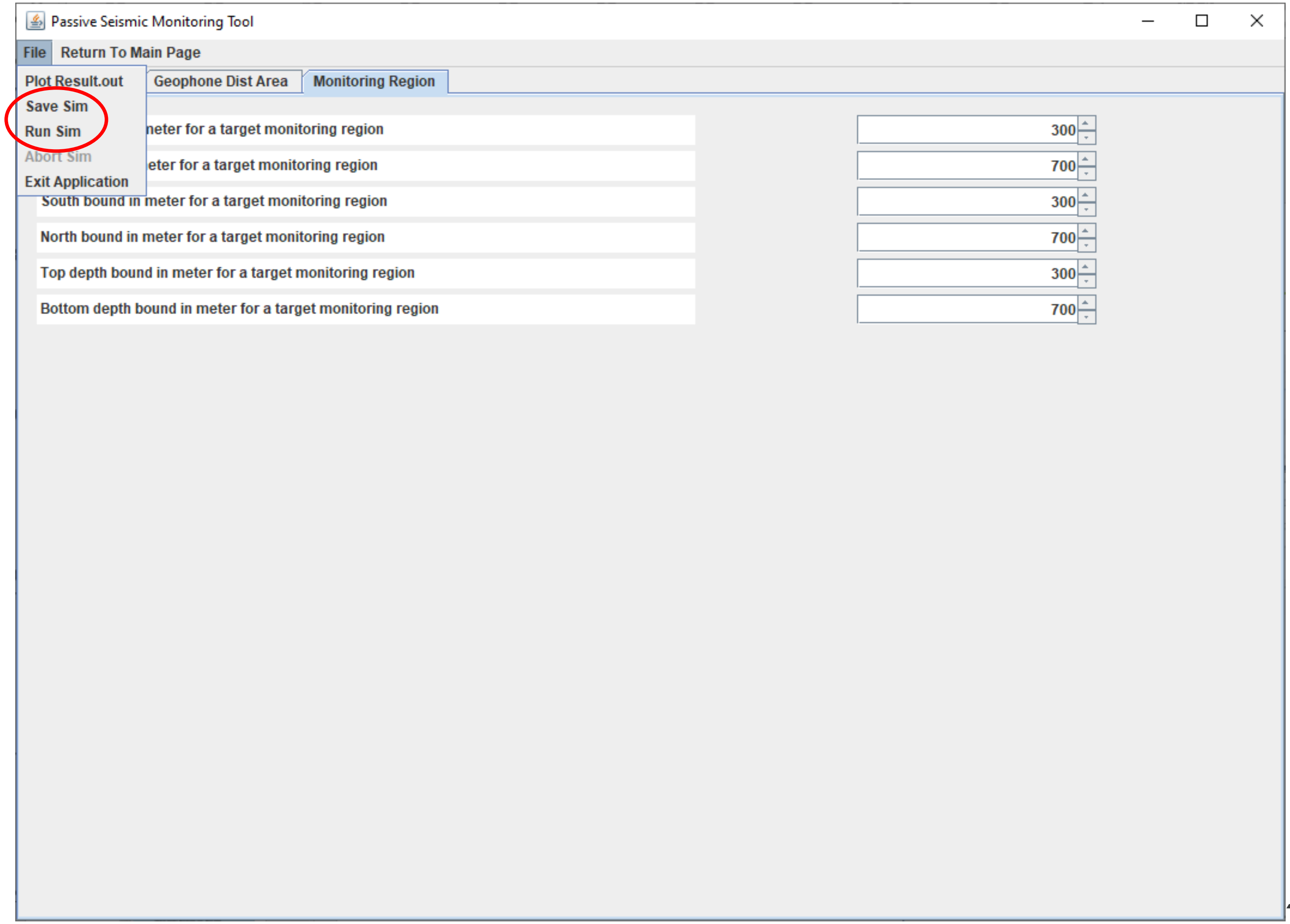
NRAP Tool


File
Plot Result.out
Save Sim
Run Sim
Abort Sim
Exit Application


Passive Seismic Monitoring Tool
File
Plot Result.out
Save Sim
Run Sim
Abort Sim
Exit Application
Passive Seismic Monitoring Tool - Main Page
Enter Parameters
tool is for optimal design of microseismic monitoring network using surface or borehole
User inputs include 1D/3D velocity models, the geophone distribution area and a target
monitoring region. The tool outputs the standard deviation errors of microseismic event locations as
a function of the numbers of geophones within the geophone distribution area. The turning point of
the standard deviation error curve corresponds to the optimal/cost-effective microseismic
monitoring network.
RUN SIMULATION
Version: 2020-05-13
Main Contact: Lianjie Huang
E-mail: ljh@lanl.gov
Acknowledgements
References
User Manual
NRAP
NATIONAL ENERGY TECHNOLOGY LABORATORY
BERKELEY LAB
Los Alamos NATIONAL LABORATORY EST. 1943
Pacific Northwest NATIONAL LABORATORY

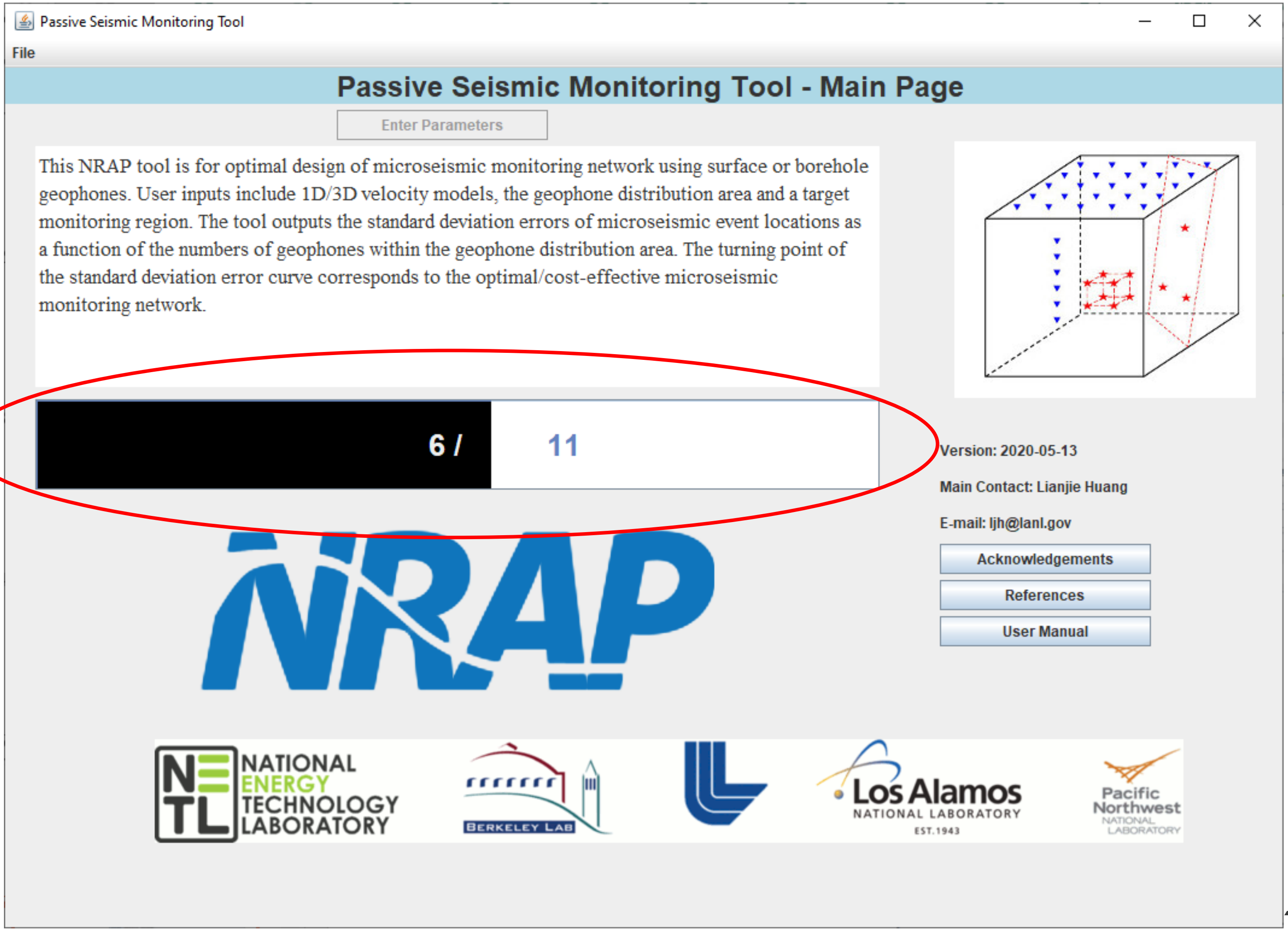
NRAP Tool

- Save parameters (Save Sim)
- Run simulation (Run Sim)



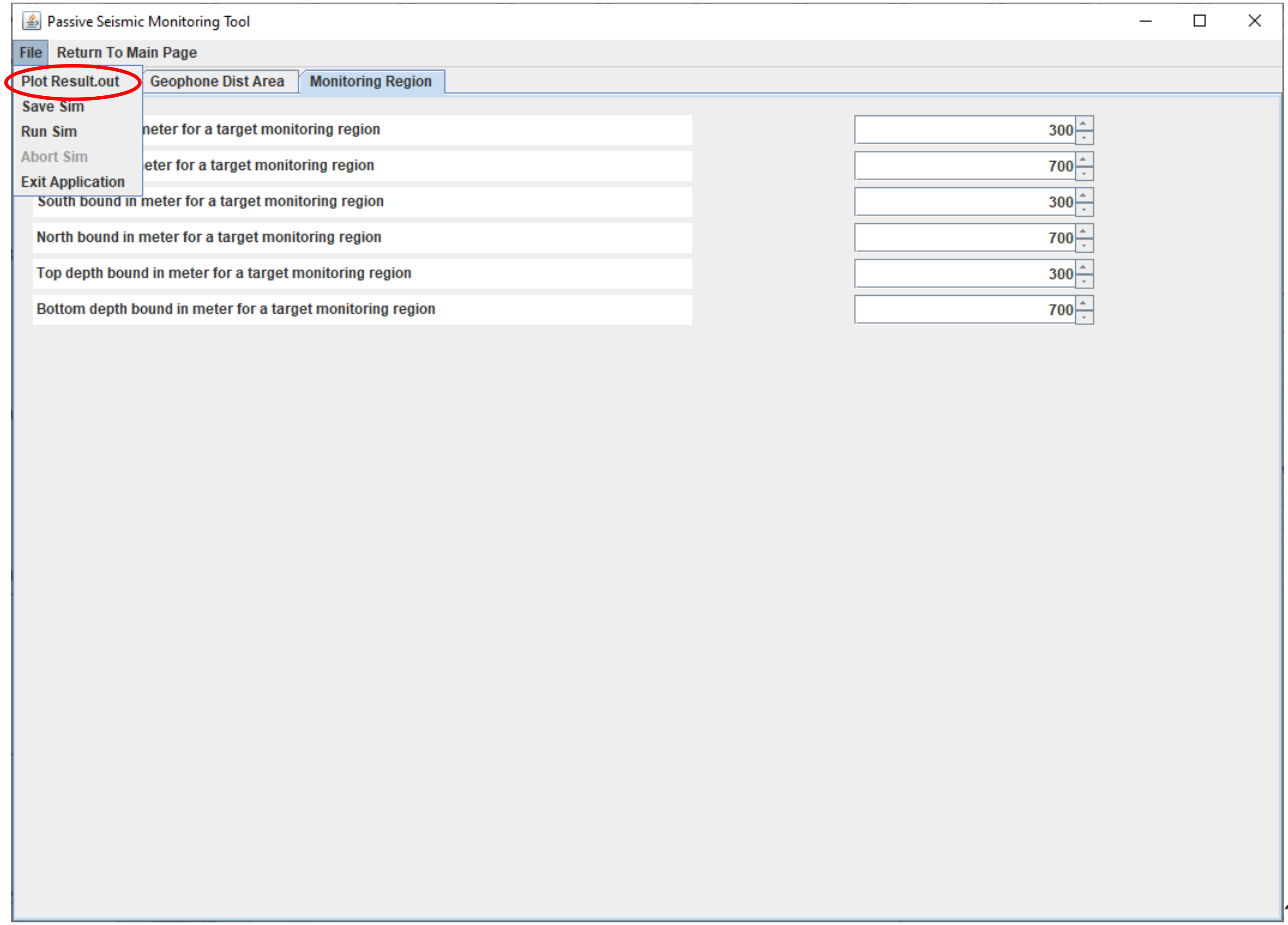
NRAP Tool

- Save parameters (Save Sim)
- Run simulation (Run Sim)
- Progress bar shows the job progress



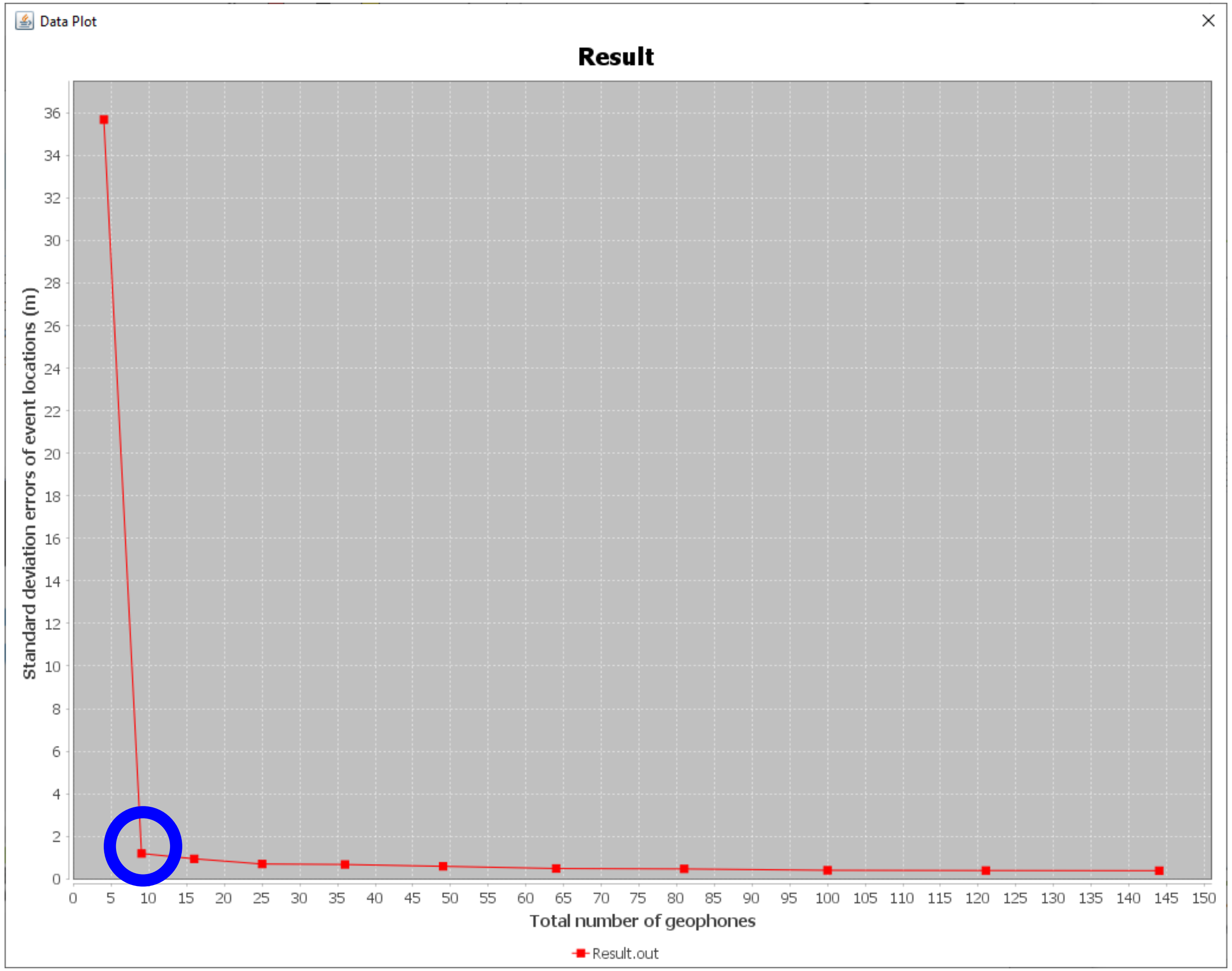
NRAP Tool

- Plot result (Result is automatically plotted after the job is completed.)



NRAP Tool

- Result of the three-layer model
  - Eight seismic stations are needed for cost-effective microseismic monitoring



Contents

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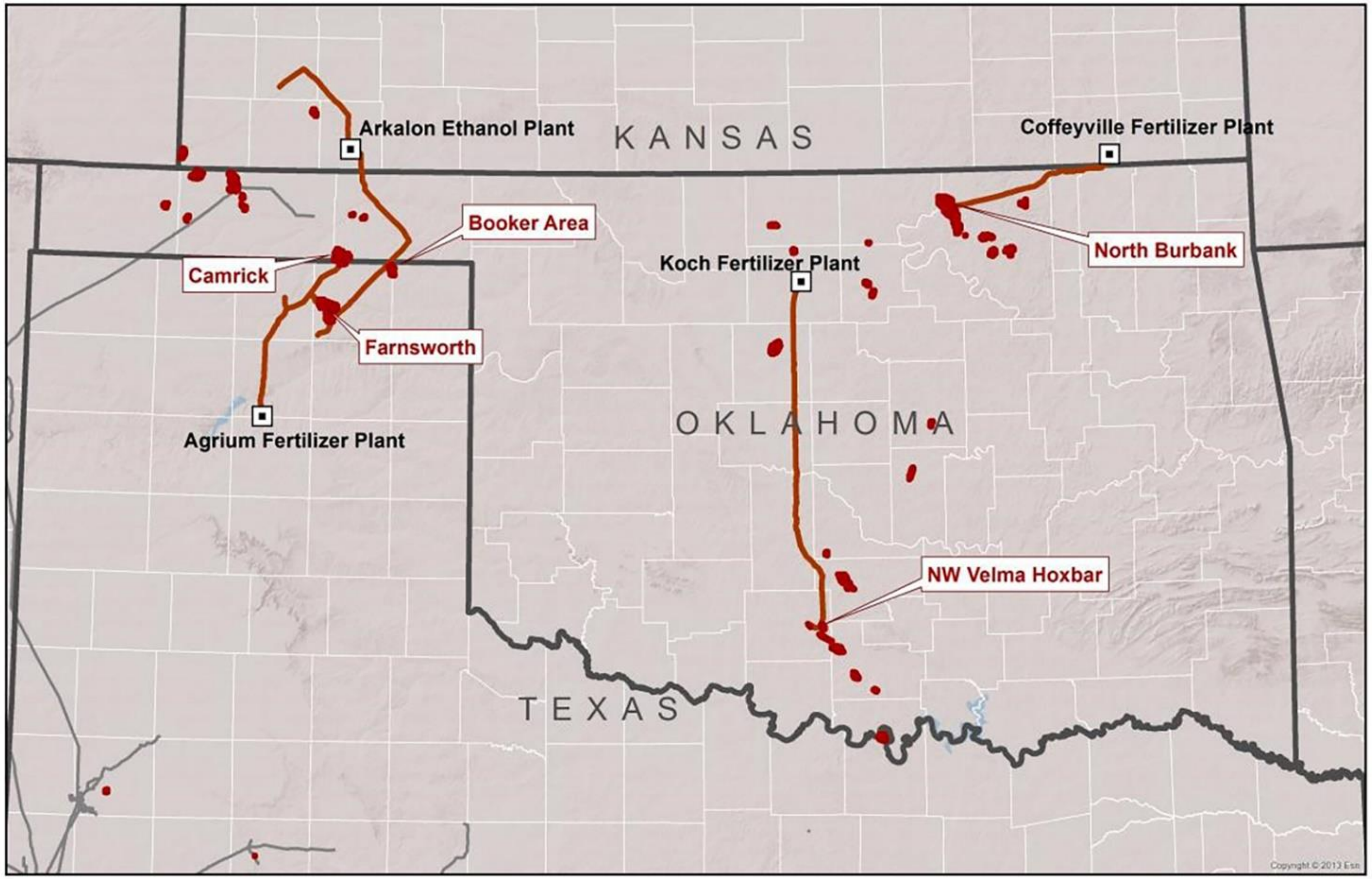
- Example application to the Farnsworth CO_2-EOR field, Texas

Farnsworth CO_2-EOR Field: SWP Phase III

(From: https://www.netl.doe.gov/coal/carbon-storage/atlas/swp/phase-III/farnsworth)



KEY PARAMETERS FOR FARNSWORTH UNIT

Depth: ~7,750 TD

Thickness: ~6.9 meters (~22.5 feet)

Porosity: ~15%

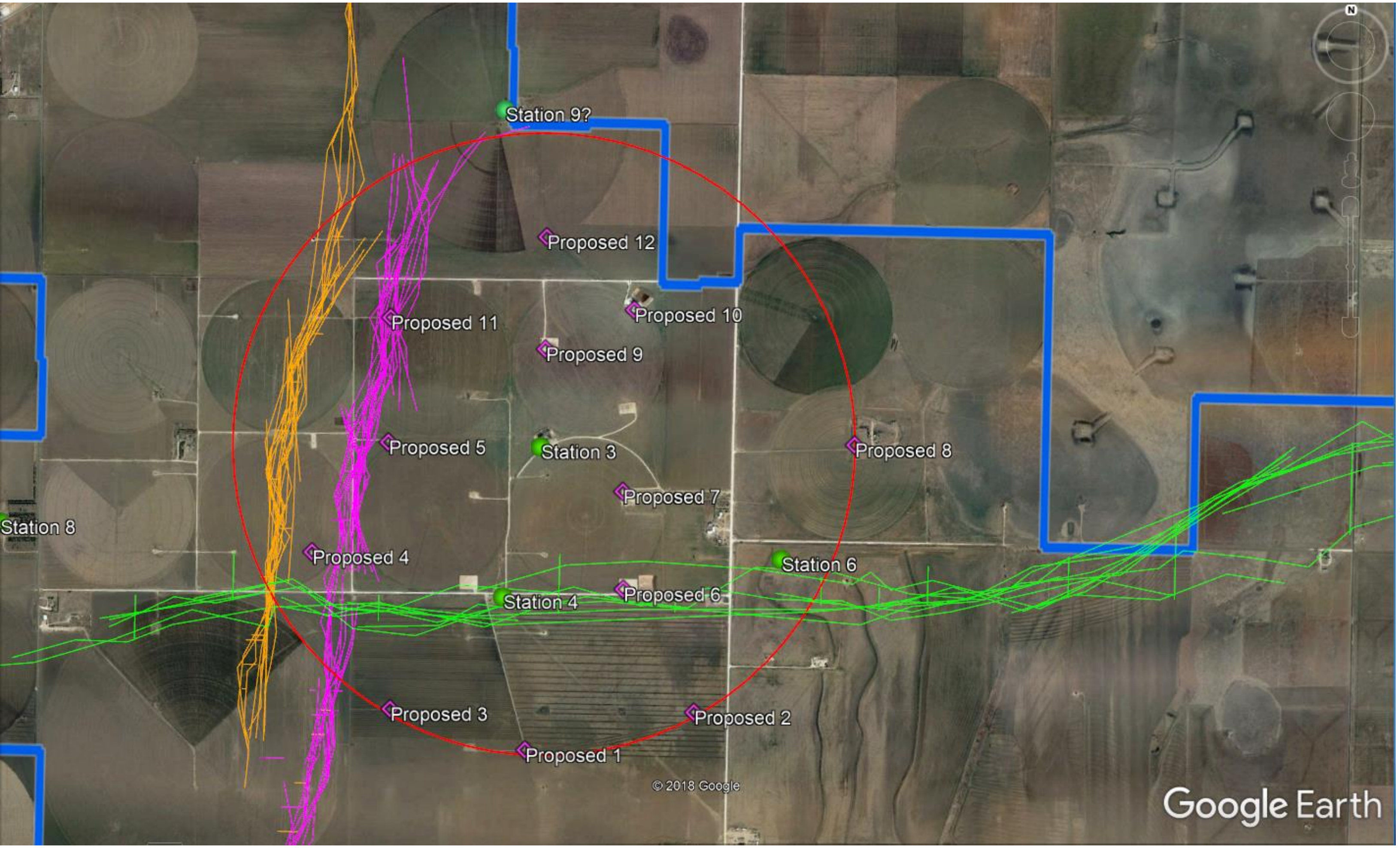
Permeability: ~65 mD, but highly variable

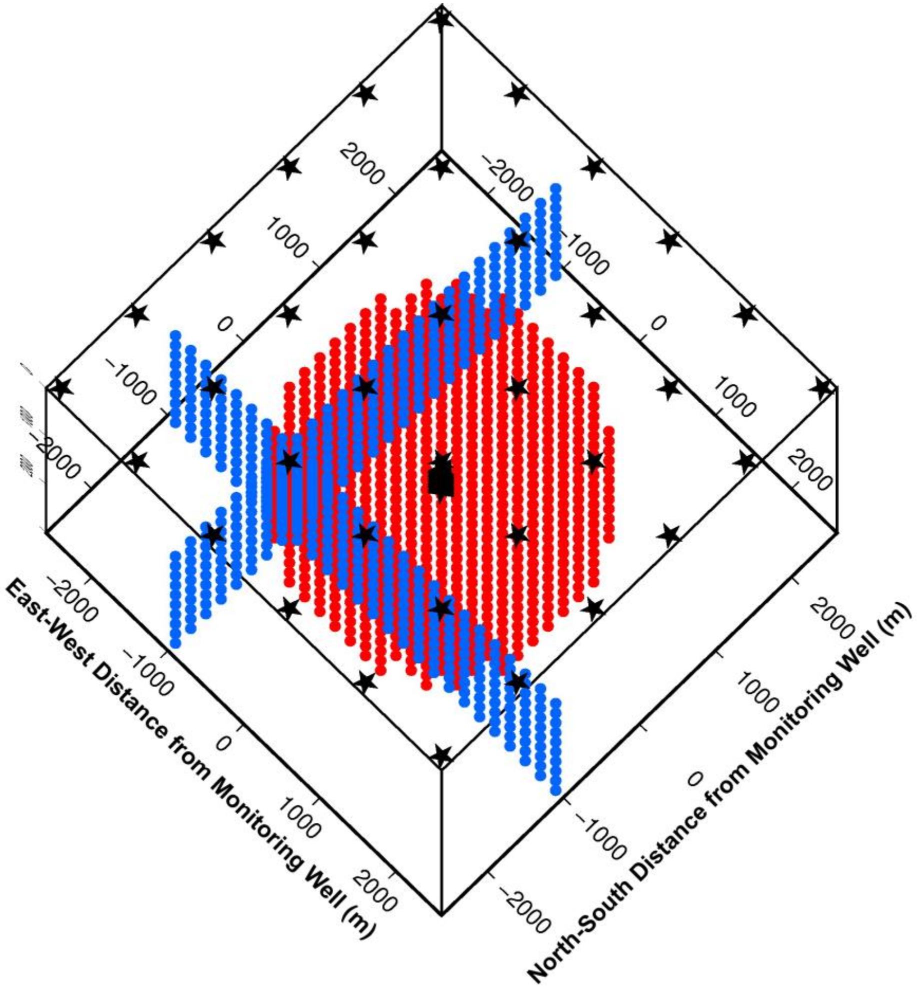
Pressure: ~4,200 psi

Temperature: ~168°F

Oil API: ~40δ

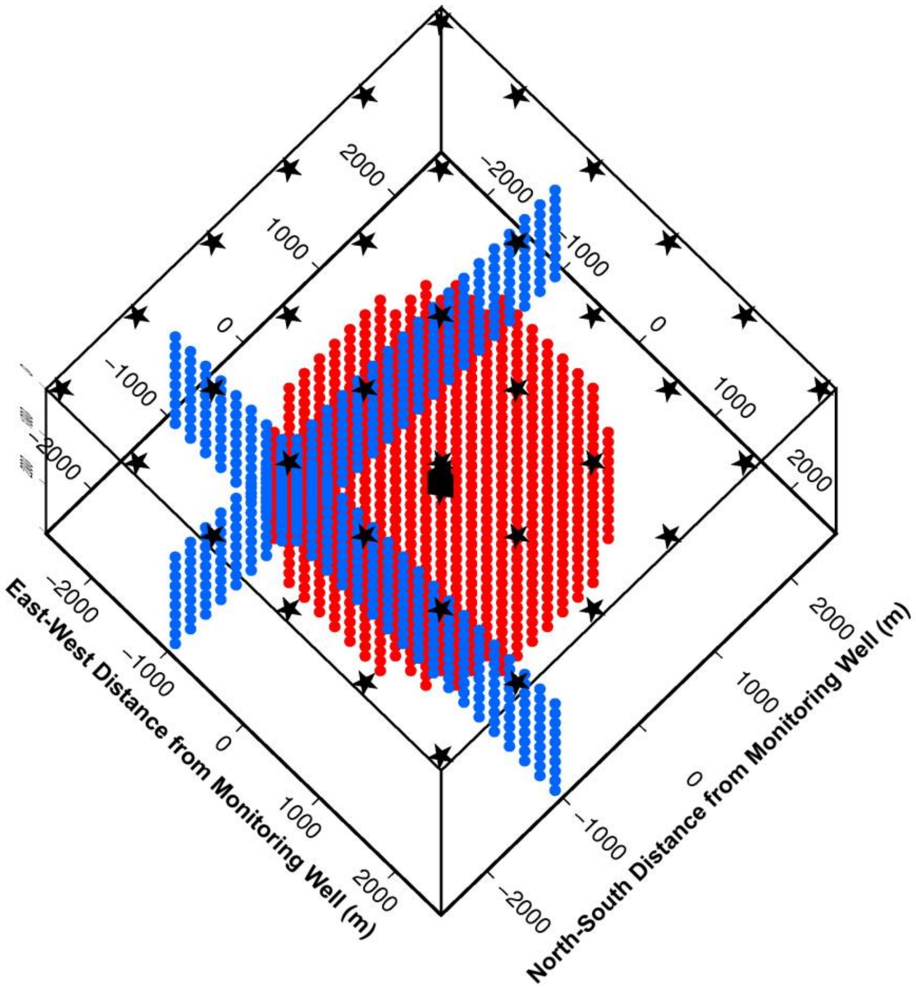
Target monitoring regions





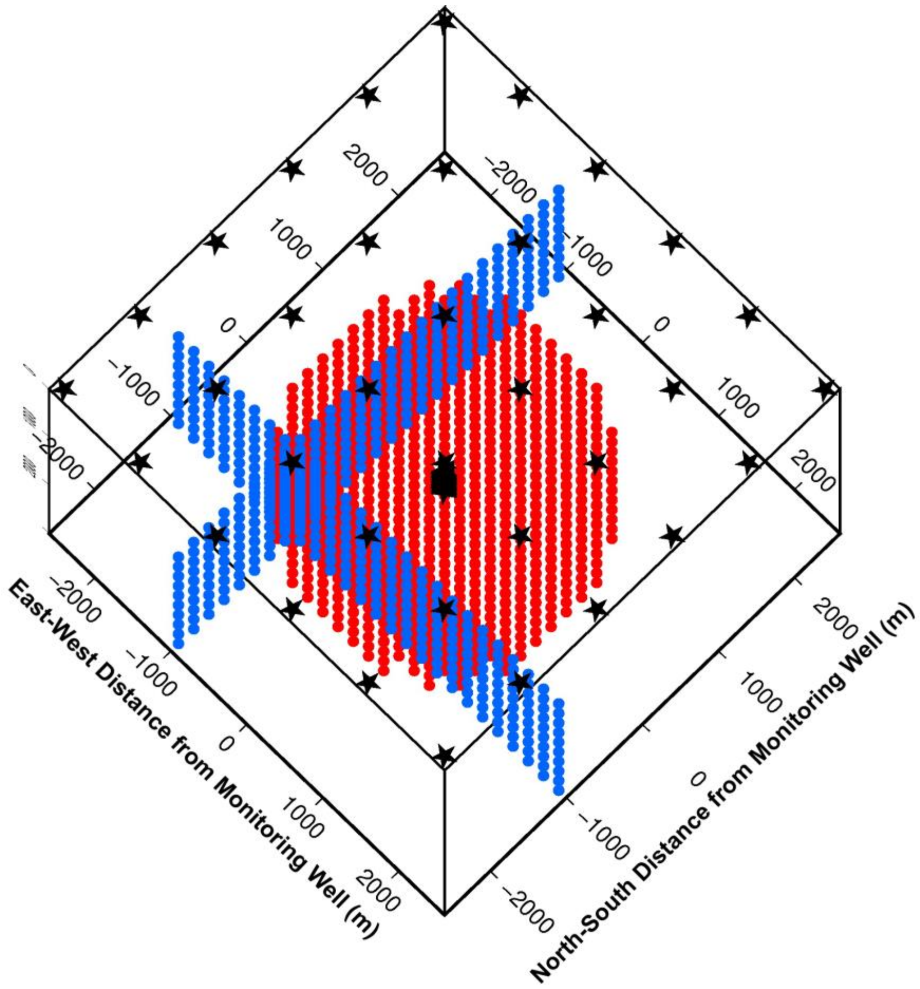
Target monitoring regions

- Reservoir: Cylinder region: Radius of 1.6 km from the monitoring well; Depth range between 1.2 km and 3.0 km.
- Faults: 5 km long; Depth range between 1.2 km and 3.0 km.
- We design synthetic microseismic events with an interval of 0.2 km for the reservoir and 0.2 km for the faults.
- There are 1737 synthetic events (red) in the reservoir volume and 520 synthetic events (blue) along the faults.
- We invert locations and focal mechanisms of synthetic events, and compute standard deviation errors of locations between synthetic events and inverted events.

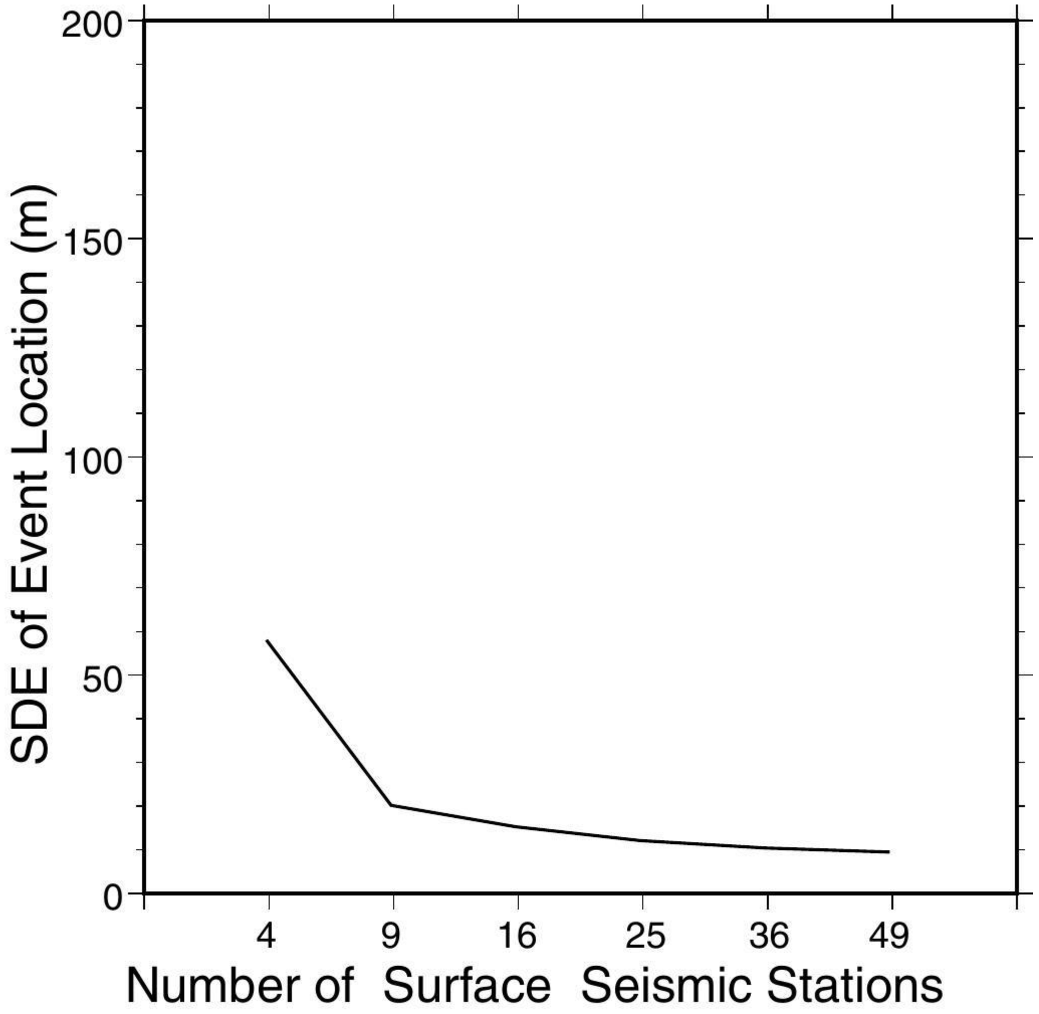


Surface network design

- There is a borehole monitoring array with 16 3-C geophones spanning from 1.6 km to 2.1 km
- We design a square area with a side of 5 km.
- N x N surface geophones are evenly distributed in the 5 km x 5 km area.
- N is from 2 to 7, corresponding to 4 to 49 surface geophones.
- Standard deviation error of traveltime picks/velocity errors is 25 ms. Assume a normal distribution of the errors.

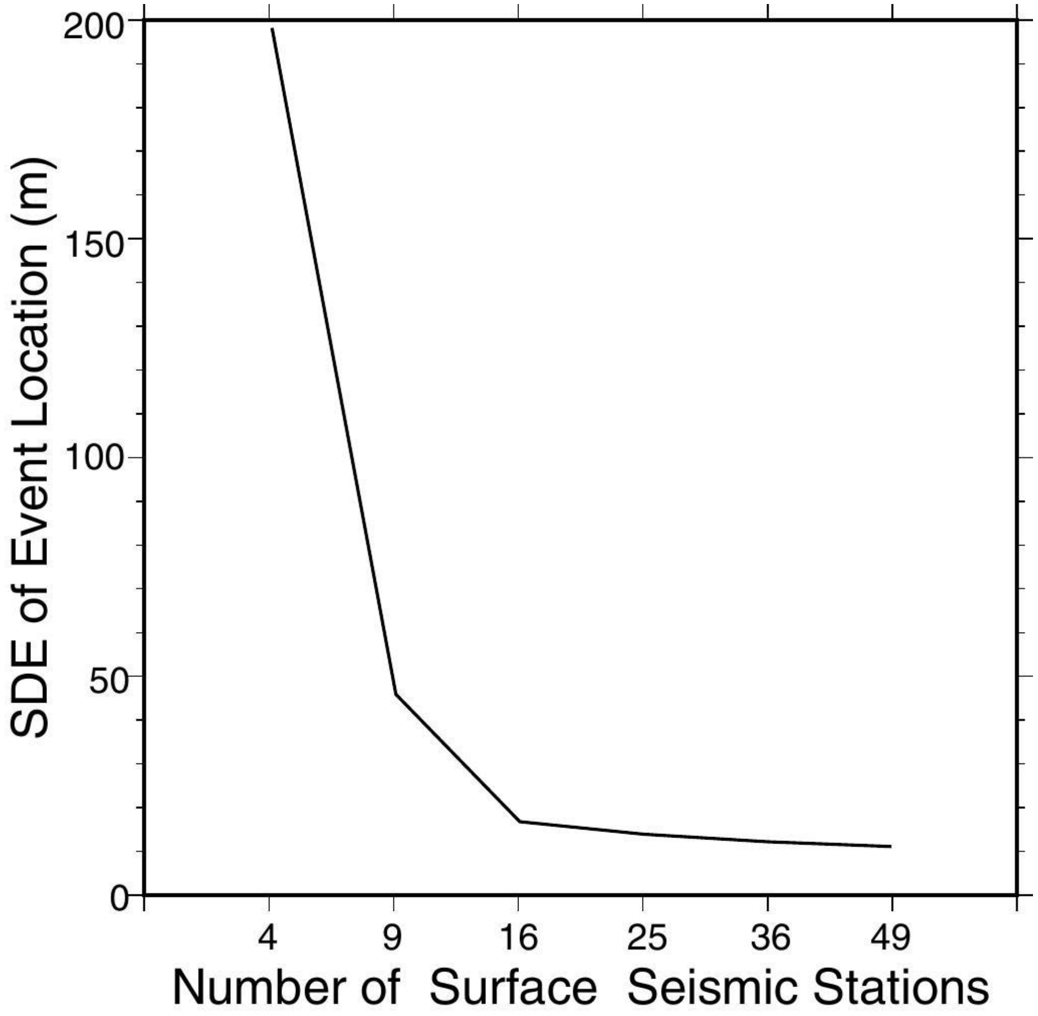


Location SDE (Reservoir)



- 9 surface seismic receivers are needed for microseismic event location in the reservoir.
- Standard deviation error (SDE) is approximately 21 m for 9 surface stations and 16.1 m for 16 stations.

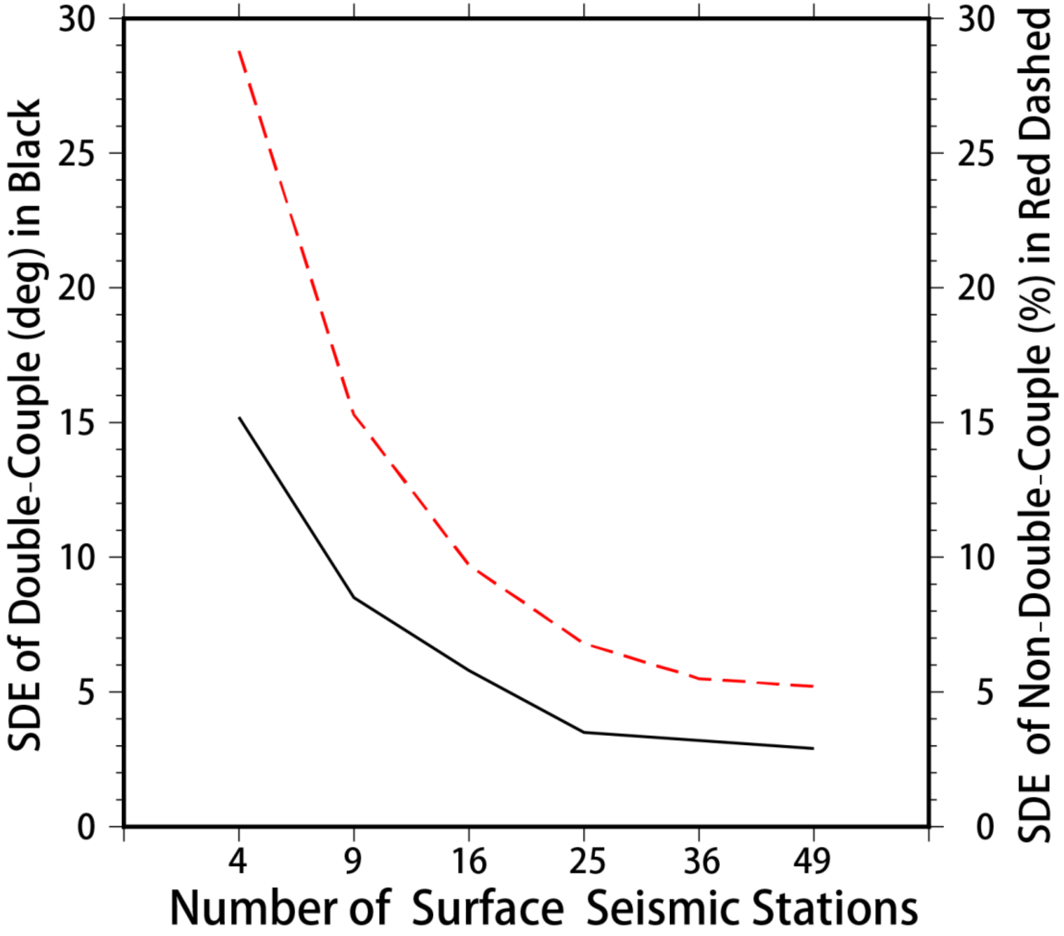
Location SDE (Faults)



- 16 surface seismic receivers are needed for microseismic event location along the faults.

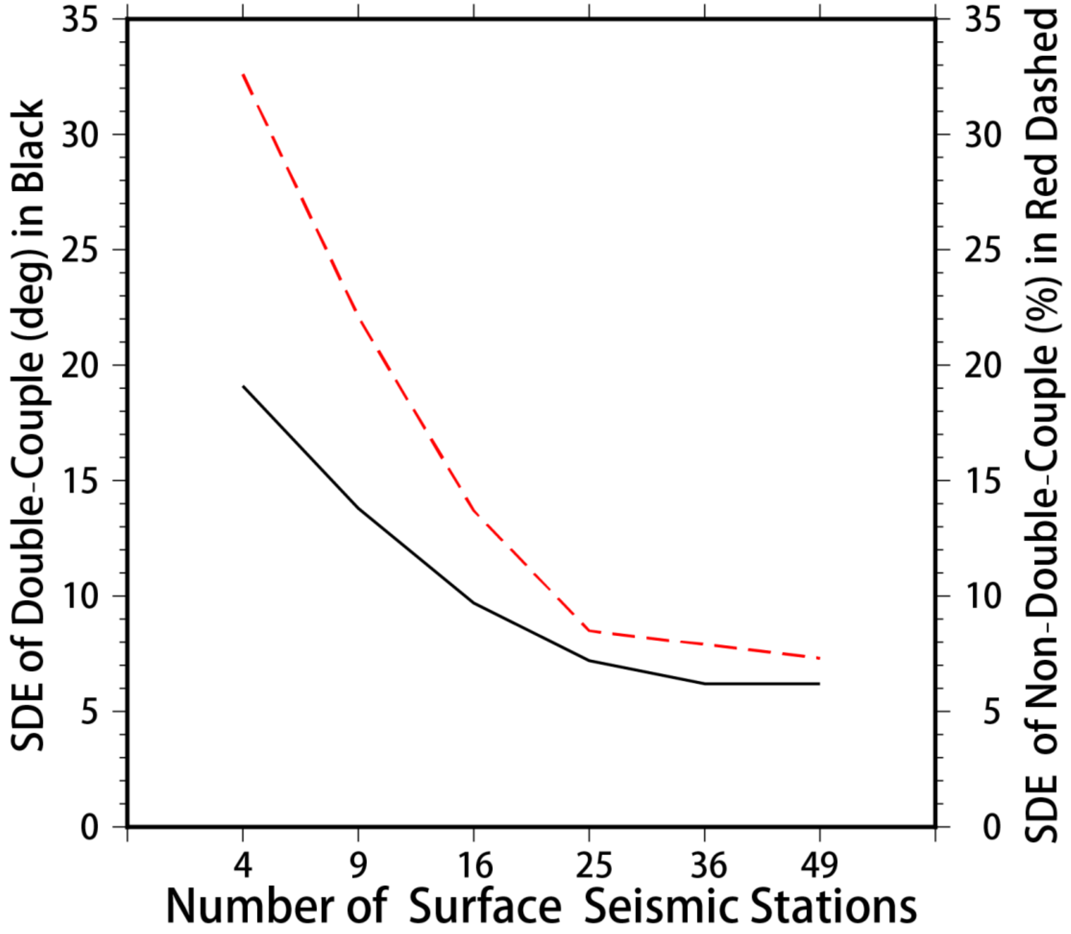
- Standard deviation error is approximately 17.5 m.

Focal mechanism SDE (Reservoir)



- 25 surface seismic receivers are needed for focal mechanism inversion of microseismic events in the reservoir.
- Standard deviation errors are approximately 4 deg for double-couple component and 5 % for non-double-couple component.

Focal mechanism SDE (Faults)



- 25 surface seismic receivers are needed for focal mechanism inversion of microseismic events along the faults.

- Standard deviation errors are approximately 7 deg for double-couple component and 9 % for non-double-couple component.

Locations of 25 seismic stations

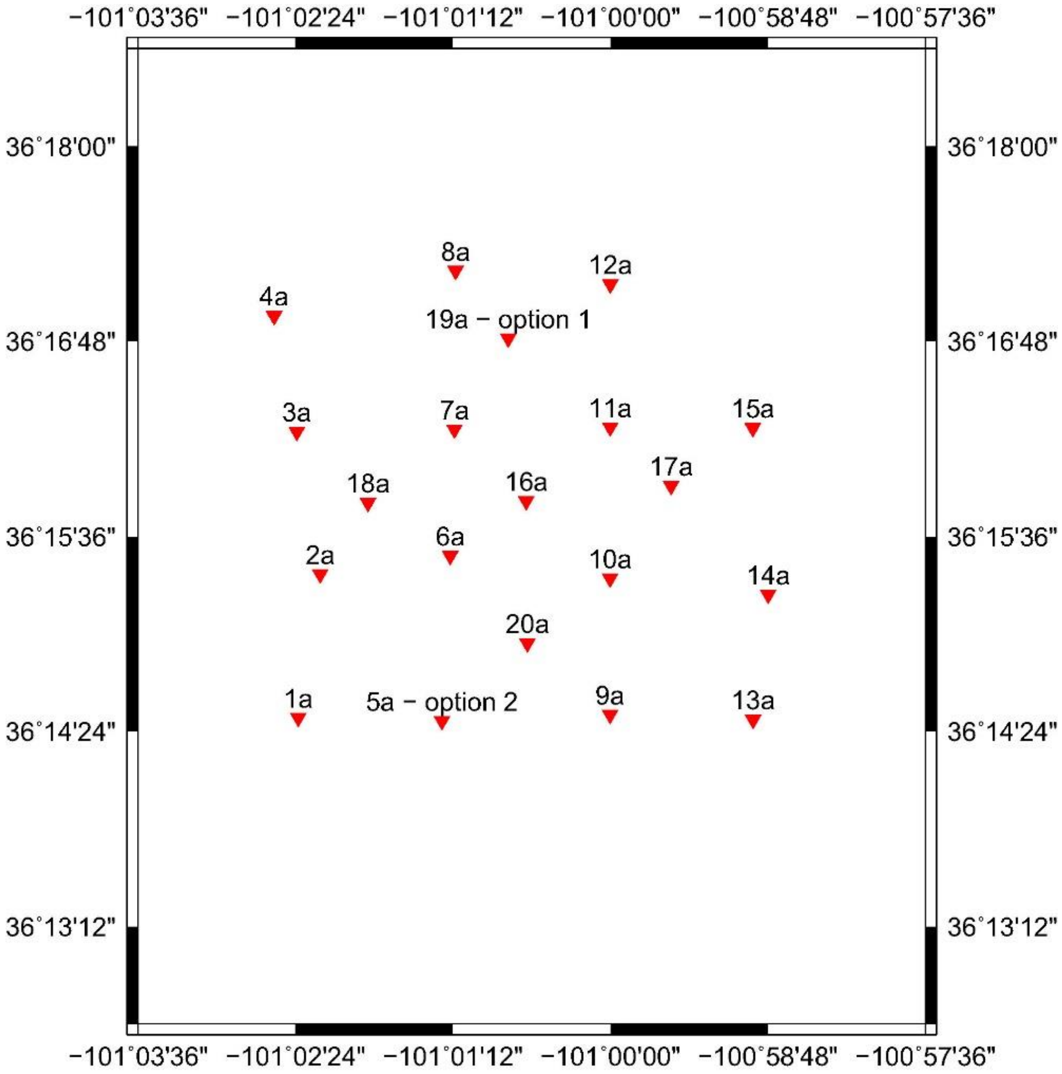
No.	X(m)	Y(m)	Lon(deg)	Lat(deg)
1	-2.50	-2.50	-101.038640	36.241077
2	-2.50	-1.25	-101.038640	36.252339
3	-2.50	0.00	-101.038640	36.263600
4	-2.50	1.25	-101.038640	36.274861
5	-2.50	2.50	-101.038640	36.286123
6	-1.25	-2.50	-101.024674	36.241077
7	-1.25	-1.25	-101.024674	36.252339
8	-1.25	0.00	-101.024674	36.263600
9	-1.25	1.25	-101.024674	36.274861
10	-1.25	2.50	-101.024674	36.286123
11	0.00	-2.50	-101.010707	36.241077
12	0.00	-1.25	-101.010707	36.252339
13	0.00	0.00	-101.010707	36.263600

No.	X(m)	Y(m)	Lon(deg)	Lat(deg)
14	0.00	1.25	-101.010707	36.274861
15	0.00	2.50	-101.010707	36.286123
16	1.25	-2.50	-100.996740	36.241077
17	1.25	-1.25	-100.996740	36.252339
18	1.25	0.00	-100.996740	36.263600
19	1.25	1.25	-100.996740	36.274861
20	1.25	2.50	-100.996740	36.286123
21	2.50	-2.50	-100.982774	36.241077
22	2.50	-1.25	-100.982774	36.252339
23	2.50	0.00	-100.982774	36.263600
24	2.50	1.25	-100.982774	36.274861
25	2.50	2.50	-100.982774	36.286123

Updated with a given geophone distribution

Standard Deviation Errors (SDE) for the scenario in the figure on the right:

- SDE of event location for the reservoir: 15.5 m
- SDE of event location for the two faults: 17.2 m
- SDE of focal mechanism for the reservoir: 5 degree (DC); 7% (Non-DC)
- SDE of focal mechanism for the two faults: 7 degree (DC); 10% (Non-DC)



Summary

- An NRAP tool on optimal design of microseismic monitoring network is available at NETL EDX for geologic carbon storage and other microseismic monitoring applications: https://edx.netl.doe.gov/user/register.
- The example application of the tool to the Farnsworth CO_2-EOR field shows that
  - 9 surface seismic stations are needed for microseismic event location in the reservoir and the faults.
  - 25 surface seismic receivers are needed for focal mechanism inversion of microseismic events in the reservoir and the faults (this capability is not included in the current release of the tool).

Thank you!

NRAP
National Risk Assessment Partnership

Comments and Questions:

NRAP@NETL.doe.gov

NRAP Website: https://edx.netl.doe.gov/nrap/

Sign up for NETL EDX: https://edx.netl.doe.gov/user/register